How to Build Quantum Models of Consciousness

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Abstract

Science is learning more about the brain activity necessary for consciousness, but has not identified any mechanisms for how it could actually arise through neural processes. Here I present ways to build consciousness into the mathematics of quantum mechanics for use in the growing area of quantum neurology. Quantum waves are not physical in the sense of forces acting on particles through cause and effect, and they are expressed using mathematical placeholders that do not have agreed-upon real-world representations. These can be used to represent consciousness. Quantum mechanics has shown how the traditional aspects of the physical world emerge from non-physical quantum information through a combination of mathematical, not causal, determinism, and stochastic interactions. The modeling methods here could help account for how the mental world could also emerge from information fields.

Neural interactions for mental experiences are complex, so it is reasonable to expect that consciousness is an emergent property of neural networks. But emergent properties are not magic – they work through procedural mechanisms – in this case for how neural processes generate experiences. No steps for how consciousness could be manufactured in this way are apparent, and philosophers have strong arguments for such not being possible. An alternative is to model consciousness as part of quantum waves, so it is accessed, not created, by the brain. This is a form of neutral monism – the idea that the physical and mental worlds both come from a single underlying source – in this case quantum waves.

The classical physical picture of particles and forces acting under cause and effect has developed into a belief system, not just a theory, and this has created difficulties in taking quantum mechanics itself at face value. The result has been the creation of numerous "interpretations" of quantum mechanics that seek to frame it within these philosophical presuppositions. The conceptual framework of Cartesian dualism provides a platform for analysis of the related philosophical issues of consciousness and of quantum mechanics itself.

Keywords: Consciousness, Quantum, Neurology, Dualism, Many-Worlds

1. Introduction

Russell (1927) cautions against believing that the physical world is fundamentally different from conscious experience ("percepts"): "Physics, in itself, is exceedingly abstract, and reveals only certain mathematical characteristics of the material with which it deals. It does not tell us anything as to the intrinsic character of this material." And: "The gulf between percepts and physics is not a gulf as regards intrinsic quality, for we know nothing of the intrinsic quality of the physical world, and therefore do not know whether it is, or is not, very different from that of percepts."

The once-common view that particles and forces are intrinsic qualities of the world is not maintained in quantum mechanics. These instead are produced by underlying processes that might produce conscious experience as well. In fact, consciousness has been proposed as part of quantum mechanics since its inception. An early suggestion was that quantum waves could turn into particles by dint of someone's conscious observance of a measurement. Another proposal has been that human experience arises by the brain accessing a conscious potential in the quantum field. Ideas like these have some credibility because quantum waves are packages of information about possible physical properties, not waves of forces.

Quantum mechanics is described conceptually below within the framework of Cartesian dualism, and models that build in consciousness are laid out from there. Descartes postulated separate mental and physical substances, but the idea of substances has not fared well. Particles in particular do not exist in quantum-mechanical formalism. Instead, the building blocks of atoms are waves in quantum space, and do not consist of physical substance. What they actually are is a major issue in trying to understand physics – encapsulated by the question "what's waving?" The models considered here postulate that these waves have mental and physical aspects, and underlie mind as well as matter.

Like the original Cartesian dualism and modern panpsychism, this avoids the "hard problem" of how thinking and experiencing can arise from matter alone. It still has to deal with the pretty hard problem of how the brain can interact with whatever awareness-potential might already exist. There is a tendency for physics to not look too closely at the non-material aspects of quantum theory, in part due to an antiquated view of a purely physical universe. This is actually one of the traditional philosophical alternatives to dualism.

We begin in section 2 with a brief review of Cartesian dualism and its historical alternatives – which hold that only one of mental and physical substance really exists, and the other is produced from it, or else that there is something they both arise from. Philosophers find all of these positions problematic in some way.

The success of Newtonian physics locked some of the pre-quantum scientific world into one of these positions so rigidly that it has proven hard to get beyond it. Section 3 looks at quantum mechanics from a largely conceptual viewpoint to show what the world looks like from its standpoint, and in particular how the physical aspects of atoms emerge from information waves. Section 4 specifies the quantum-consciousness models. Section 5 looks in more detail into a key part of quantum theory – coherence – which has been a large reason that traditionally physical models do not work at the micro level. It has also been used in some accounts of consciousness. Section 6 addresses the interaction issue – how the brain and mind could interact under these models and other approaches. The growing field of quantum neurology provides models that could combine with quantum-consciousness models to further the explanation. Section 7 concludes.

2. Background

Cartesian dualism postulates mental and physical substances that interact in the brain to produce thoughts and other experiences. Philosophers have always been skeptical of it, due to difficulty in imagining how two such fundamentally different substances could interact – the pretty hard problem. Dualism's chief alternatives are physical and mental monism – often referred to as physicalism and idealism, not used much here as those terms have other meanings – that hold that just one of the substances is real and the other is created from it. Another alternative is neutral monism, which holds that both arise from one single underlying thing. Here these terms are used more broadly – no substances are required, as nothing fundamental seems to be made out of substances these days. So dualism here is any approach where mind and matter are separate, with neither deriving from the other.

Physical monism holds that experience will someday be shown to arise purely from physical processes. Philosophers have been skeptical of this as well, again not being able to imagine how it could happen. Chalmers (1995) calls showing how consciousness could come from physical processes "the hard problem." He looks at models of neural processes and finds they include only physical interactions, with no suggestion of how they could produce experience. Physical monists like the idea that consciousness is an emergent property of complex neural systems, but saying that does not provide a mechanism for how it could emerge – so it does not really address the hard problem. Somebody – probably Karl Popper – once remarked that a poor imagination is not evidence of anything. Considering this, philosophers do not feel they have disproved dualism or physical monism, but most remain skeptical of them. Many lately feel that physicalism has the more daunting challenge.

Panpsychism, which Goff (2017) defines as the view that consciousness pervades the universe and is a fundamental feature of it, is a form of dualism gaining popularity recently. The conscious-wave models proposed here take a similar point of view, with some element of consciousness in every quantum wave, but are slightly different, as it is not clear that quantum waves reside totally within physical space. Panpsychism has an aggregation problem – how all those bits of consciousness could combine to give experiences. Most neural activity is not experienced, but might be a kind of background noise that aggregation could overwhelm. The conscious-wave models have the same problem. Some of the brain studies discussed below find a high degree of redundant repetition in neural activity related to conscious experience, and that is a possible avenue of aggregation.

Strawson (2008) calls the view that "physical stuff is, in itself, in its fundamental nature, something wholly and utterly nonexperiential" the faith of "physicsalism." Looking at how these beliefs are expressed today, I add the belief in determinism as a second tenet of the faith, and call it, and its adherents, physicalistics.

Such beliefs arose historically from the successes of Newton's laws. His mechanics theoretically allows the calculation of any future state of every particle from all of their current states. This gives us a picture of a causal, clockwork universe. Laplace noted that in such a place, a vast intellect who knows the state of every object would then be able to compute everything that has ever happened or would ever happen. The believers in this faith do not have to believe in Laplace's demon, just in her possibility. She is a quasi-deity for a quasi-religion.

The hypothesis that the universe is causal was a good one to make post-Newton. It is a strong hypothesis, and could be refuted if further investigation found it to be faulty in some way. It became more than a hypothesis, though, being adopted as an irrefutable world-view by many. Freese (2008) characterizes views like that as "more vampirical than empirical – unable to be killed by mere evidence." Combined with the idea that mental phenomena would be eventually explained physically, causality became a physicalistic faith that included thought, speech and action. Usually learned with classical physics in high school, the belief by some students in unchallengable causality engenders rampant debates about determinism and free will – which itself is poorly enough defined that such discussions can continue endlessly.

The physicalistics have developed defenses to maintain their beliefs against the problems that quantum mechanics poses for it – like events that follow probability but not causation. One defense is the "shut up and calculate" response: use the math but don't think about what it means. Another is the so-called interpretations of quantum mechanics, used to make sense of it within this faith. These are theories that go beyond the science and may build elaborate invisible extensions of it – such as multiple universes or particles following pilot waves – or might even deny that the macro world we know of is made from micro components.

The other chief historical alternative to dualism is mental monism, or idealism. This holds that the only thing we directly know about is experience. Everything else is postulated – things like causation, the physical world, etc. We can never verify these things directly – we only directly observe experiences – so we cannot consider scientific theories to be a form of knowledge. Experience is the entirety of the universe we really know about. One approach to that is looking on what we experience as "sense data" and holding that everything else is a theory built from that data. For instance, Hume considered watching one billiard ball hitting another, stopping, and the other one starting to move away. There is no experience of causation specifically observed, so that is not a thing we know, only something we surmise.

Benson Mates, a philosopher at UC Berkeley, was a scholar more than an advocate. See e.g., Mates (1953). Once the philosopher Samuel Johnson, to disprove idealism, kicked a large stone and when his foot did not pass through said "I refute it thus." Mates and others reject the argument in part on the basis that the idealists would have expected that outcome. He felt that idealists could use physical theories to make predictions without accepting physical objects as real things. This is "shut up and calculate" applied to rejecting the existence of the physical universe. It is a versatile tool.

My objection to its use by either branch of monism is that it comes from too limited a view of the nature and role of models in science. Box (2008) famously said that all models are wrong but some are useful. (Other statisticians have struggled to make that specific, e.g., see https://statmodeling.stat.columbia.edu/2008/06/12/all_models_are/ . A lot of the theory of statistical accuracy starts by assuming the data came from the modeled process.) Models are approximations of more general processes, and none can be considered as absolute truth. They still can be useful, of course for prediction, within some bands, and also for providing a way to conceptualize and understand the processes. Even if ultimately lacking in some regard, models provide a framework and vocabulary for visualizing and discussing complicated observations. Models that are successful in predictions use frameworks that deserve consideration as explanations of underlying phenomena. Even if ultimately some future, more refined models are likely to supersede them, they still work well in their realms and should be taken as useful ways to visualize what is going on.

The physicalistics use of the phrase "shut up and calculate" often comes along with the assertion that physics is about making predictions, not about understanding the world – the latter is the subject of philosophy. This idea makes physics a branch of engineering. It also makes it the only science that has abandoned trying to understand the world. At least one of my quantum mechanics professors at Berkeley was ok with this. He said that engineering is like physics, just harder. After waiting for the gasps to die down, he explained that physics gets to make a lot of simplifications, like frictionless flow, where engineering has to include all the messy details. Nonetheless, people like me left physics at that point, not really caring much about making predictions.

Neutral monism – the idea that mind and matter both come from something more basic – has always been a possibility, but no obvious candidates have arisen, and it doubles the interaction problem. Now mind and matter each have to interact with something different than both but still not likely to be much like either.

Another way to dodge looking for any representation of quantum mechanics in the world we know is to jump to ultimate reality being more complicated than any model, and conclude that we might as well treat the quantum world as being purely mathematical. Carroll (2019), for instance, would like to have a realistic theory of quantum mechanics: "Physicists were left with the question that we are still struggling with today: What *is* the wave function, really? What physical thing does it represent, if any?" But lacking an answer, in the interpretation he espouses, he advocates the idea that we live inside a Hilbert space, which is a high-dimension mathematical object. He may have meant that the physical world has the structure of a Hilbert space, most of it out of sight to us, not that it really is one. In any case, saying that the quantum reality is purely mathematical is better than not discussing what it means at all, but still avoids saying anything about the nature of the quantum waves. More generally the idea that we live in a mathematical object could be seen as a type of idealism – the physical world in the end exists in an entity invented by the mind.

3. How Physical Atoms Emerge from Non-physical Quantum Waves

Physics has traditionally described the world in terms of waves and particles, but particles are not part of the formalism of quantum mechanics. Furthermore, the quantum waves themselves are not physical, like waves of force fields. Instead, they are waves of information about possibilities. They are not physical in the traditional sense, because the wave values are not physical properties, like energy. Quantum waves move according to a mathematical determinism, and the wave values provide probabilities about what the physical properties might be. The probabilistic aspect comes without any causal mechanism and leaves a purely random element in what happens. All of this generates the basic question "What's waving?" The components of the waves in the proposed models below give a way to address that.

A number of interpretations of quantum mechanics have been introduced, often by adding in particles in some way, and by finding ways to keep an underlying determinism. Still, the growing trend in quantum theory is to make do without particles. For example, Carroll (2019) keeps determinism but has several comments about particles not being needed:

- "Atoms aren't mostly empty space; they are described by wave functions that stretch throughout the extent of the atom."
- "Quantum mechanics ultimately unified particles and fields into a single entity, the wave function."
- "Quantum reality is a wave function;"

This view considers the waves to be what is real even though they are not entirely physical. We will see below how largely physical objects like atoms and molecules arise from these information waves.

The traditional conception of particles was framed by Newton (1704): "... God in the Beginning form'd Matter in solid, massy, hard, impenetrable Particles ... " Protons, and even atoms, are somewhat like that, if you do not look too closely. They are though composite objects built up of parts – quark and electron waves – that do not have those properties. Still, once you are out of the very small scale, it works fine to model atoms and protons as particles. It is often convenient to think of particles informally as something small given the scale of focus. A beach is made of particles of sand, a BB can be a particle if used in target practice, and a golf ball seems like a particle when watching a long drive on TV. Waves that are highly localized in space are often described as particle-like, or informally as just particles.

Besides size, there is another good reason that thinking in particle terms has been resilient: a lot of observations get unitized. If a shining light imparts energy to an atom, this energy is not spread around. A single electron will jump outward to a larger shell, further from the nucleus. Light also has aspects of this, the photons. That is why the term "quanta" arose in the first place. As the theory developed, however, it worked better to think formally in terms of small wave packets, but to informally keep the particle terminology as often convenient.

An atom that absorbs a photon will eventually emit one when an electron jumps down to a lower shell. These "quantum jumps" are not intuitive from macro experience. For one thing, they are instantaneous – the electron quantum wave does not gradually move in or out. It's information just jumps. The jumps are also stochastic. When one will take place, what shell the electron moves to, and the energy and direction of an ejected photon have no identifiable causes. But if the process is observed over and over, the jumps follow a coordinated set of probability distributions. These are what the quantum information waves describe.

The lack of exact causation has been hard to accept by those of the physicalistic mindset. The tenet of determinism is severely challenged by the data, and appears not to apply at the micro level. Interpretations of quantum mechanics add in unobservable things, like parallel universes, to try to hold on to determinism. For instance, the multi-worlds interpretation says that when an excited electron can decay to a smaller shell, the universe branches off into many alternative universes. Every possible time of decay and direction of the ejected photon happens in some universe. Each of those universes is defined by the series of quantum jumps that it has had. Laplace's demon could know what will happen in every one of these future universes, so overall determinism is maintained. What seems to be random to any observer is just the necessary consequence of ending up in a specific universe. This story, however, does not get rid of the quantum jumps. It actually implies that there are a lot more of them. So all it accomplishes is to maintain determinism – and to make it vampirical – not destroyable empirically. The two tenets of physicalistics – determinism and a purely material universe of particles and forces – are not helpful in trying to understand quantum mechanics.

As a side note on multiple universes: there would have to be a lot of them, but the numbers are manageable. A googleplex is `10^10^10^2`, so a tower of powers of height 4. Carroll (2019) postulates numbers like that for how many universes are needed. Power towers have their own properties. For instance if a googleplex universes each split into a googleplex of new ones, that gives googleplex^2 universes. This is about `10^10^10^2.001`. That last power does not increase very fast and probably a 4-tower would always be enough. Large numbers mathematicians need for some combinations are much larger than this – in fact they can not really be expressed as towers of powers. For instance, there might be 10^{180} cells of Planck length in the observable universe. Let x_1 be the result of a power tower of 10^{180} 9s. Let x_{n+1} be a power tower of x_ns that is of height x_n. Then large numbers like Tree(3) would be still greater than x_{100}. Carroll also discusses shrinking all the new universes enough so that there is no extra mass needed. No one could tell, as everything shrinks proportionally. They would get smaller fast, but would always be well larger than $1/x_1$ meters. So mathematically the numbers needed would not be all that large or small. For someone strongly attached to the idea of determinism, the numbers are not much of a problem for multiple universes.

Probability distributions for the possible outcomes of any interactions are implied by the wave functions, which is why they have been called information waves or waves of possibilities. The waves are not waves of probabilities, but all the probabilities can be computed from the information in the waves. The probability distribution of an electron's locations is also the distribution of the spread of its electrical charge, for instance within atoms. So the information is about what is as well as what could happen. The electron is this wave and is composed of information. We look now at how such waves combine to produce atoms, which are more like physical objects, but still display information-wave behavior in some circumstances.

Atoms are pretty small – about 250,000,000 per inch. Most of their volume consists of shells of electron waves, with a tight nucleus of protons and neutrons – about 25,000 to 60,000 times smaller than the atom. The structure of atoms often taught in survey courses is analogous to the solar system, with electrons in orbits around the nucleus. This has been known to be problematic for a century or longer. The electron waves are standing waves – waves that are in fixed positions as a consequence of the relationship of their wavelengths to the space they are in. Electrons tend to remain in an atom due to electrical attraction between the electrons and the protons. The shells further out contain more electrons, but being further from the nucleus, they are also less tightly bound.

Figure 1 is an idealized picture showing the number of electrons in each shell. Figure 2 is a picture of a hydrogen atom from Stodolna et al. (2013) taken by shooting particles through it one at a time. There is only one electron in a hydrogen atom but sometimes it can be energized enough to jump to the second shell. The nucleus is in the center and has two fuzzy electron rings around it. The fuzziness is due to the location information spread in the wave. Even the shells are not completely distinct, which is true of larger atoms as well.

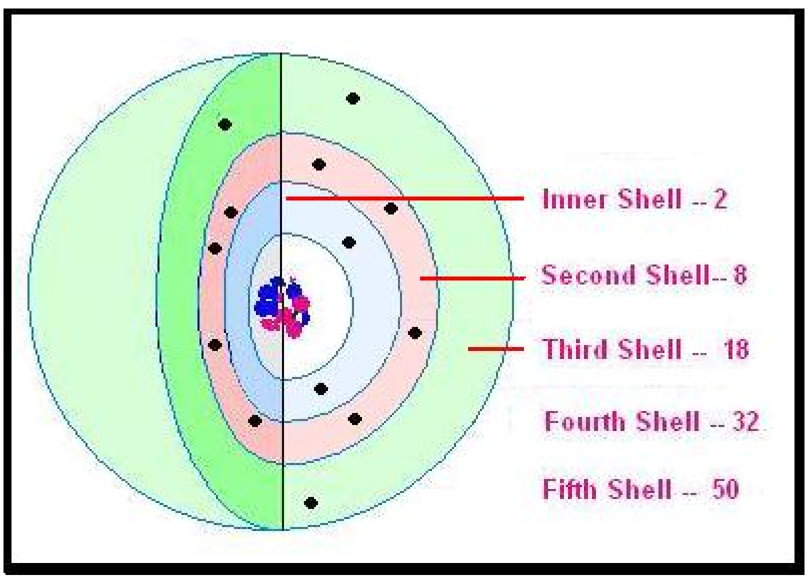

Figure 1: Structure of an Atom (Idealized)

With more than two electrons, the shells are called orbitals and are not spheres. Each electron in an atom has its own unique set of four quantum numbers that categorize all its properties. No two electrons in an atom can have the same four properties. The first quantum number is the energy level, which just says what shell the electron is in. With more energy it is in a bigger orbital, and with enough energy it is more likely to escape the atom altogether. The second quantum number goes from 0 to [1 less than the shell number] and represents

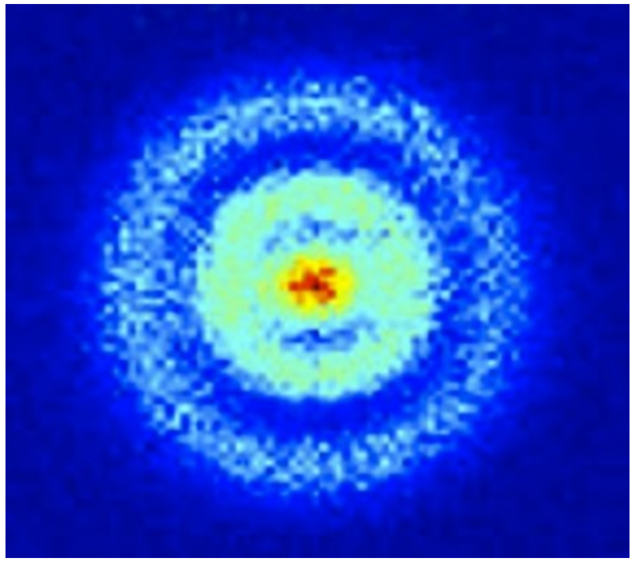

Figure 2: Hydrogen Atom

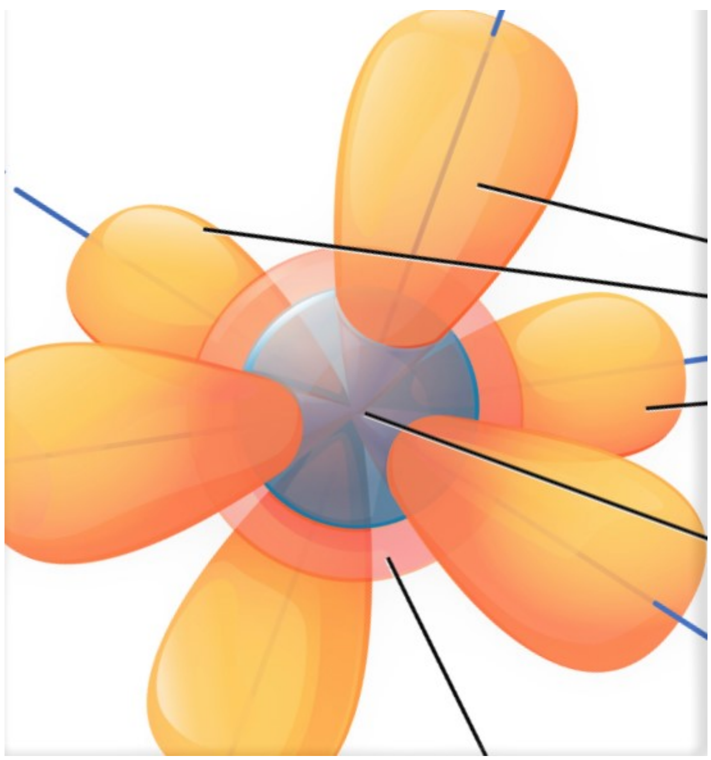

Figure 3: Atomic Orbitals

the shape of the shell. After 0 these are teardrop shapes with more petals as the number increases. Figure 3 illustrates this. Since there are more possible values of this quantum number in higher orbitals, these can have more electrons. The third number is orientation in space, which increases as the number of petals increases. The last quantum number is called spin and can only be up or down. Once all combinations of these four quantum numbers are used up for n orbitals, a new orbital is needed. From all this it is clear that in a quantum jump to a higher or lower orbital, an electron's wave shape and wave size both change.

The math of all of this comes from the quantum wave equation. It expresses how the values of the wave function change across time and location. These values determine the probability density distribution of an electron's charge and mass. The solutions of the function show where the probabilities are highest, and these tend to be on ellipsoidal shapes arranged in distinct levels. The orbital pictures represent these maximal-probability shapes, but there is some probability around each and between them. The maximum number of electrons possible in each orbital also comes out of these solutions. The fact that no two electrons with all the same quantum numbers can be in the same shell is an instance of what is called the Pauli exclusion principle. Basically it arises because the probability of an exception to it is zero. There is no Pauli force that enforces this principle – the wave probabilities going to zero are deterministic beyond any forces. Samuel Johnson's foot not passing through the stone would be predicted by Pauli's principle, but in this case, electronic repulsion of the atomic shells of the boot and stone provide a force to produce the result. Physical-world cause and effect behavior comes the quantum wave probabilities.

The determinism of the movement of wave functions is not causal in the usual sense of forces making things happen. There is zero probability of an electron being closer to the nucleus than the innermost shell. Even though the electron is drawn to the nucleus by electronic attraction, the zero probability keeps it from getting any closer, without any forces providing the resistance. To have determinism without causal forces is not physical in the usual sense, but physicalistics seem ok with this as long as Laplace's demon can keep on calculating.

The protons and neutrons in the nucleus are structures each built from three elementary wave types called quarks. Protons and neutrons themselves fit about 15 trillion per inch. Electron and quark waves have been compressed to lengths about 10,000 times smaller than this – about 10^{-19} meters. The spread of possible momentums of a quark or electron gets very large when the location gets this small, due to a complementary relationship. Most experiments and measurements end up with location measurements with fuzziness quite a bit wider than 10^{-19} meters, so from a small scale the measured locations of electrons or quarks always look like very large blobs. Thus they are somewhat compressed wave shapes but still are quite wide waves on a micro scale, and are nowhere near to being actual points. Even so, those locations can considered point-like informally if they are a fair amount smaller than the other things in the apparatus. A wave compressed to the size of the blob seems adequate to explain any data without postulating actual particles.

There is no theoretical lower limit to how small electron and quark waves can be compressed to, except for the Planck length. This is a very small distance below which space itself is thought to get too fuzzy to subdivide distinctly. The smallest squeezed electrons and quarks so far are still about a quadrillion times as wide as the Planck length.

This is the current model of how basically physical objects like atoms, and from them molecules, etc., are produced by information waves. One interpretation of it is that physicality itself is an emergent property of information waves.

4. Quantum Awareness Models

Matter as we know it is built up from something less material at the micro level. Just the idea that material substance at its core consists of information is revitalizing for Cartesian dualism in all its forms – including panpsychism. The interaction problem now seems less formidable. The mind should be able to interact with information.

Part of the mathematical formalism can add some specificity. Values taken by the quantum wave functions at any time and place are what are called complex numbers. Mathematically, the complex numbers are usually defined in a two-dimensional space. The horizontal axis of this plane is scaled by the real numbers, positive and negative, rational and irrational. These names for the various types of numbers sound like value judgments but historically they are not. The vertical axis is scaled by what they call imaginary numbers, denoted as real multiples of i. That makes them sound even less there than are irrational numbers, but it is just traditional terminology.

Complex numbers can be denoted as pairs $< a, b >$ as in any two-dimensional space, but are usually written as $a + bi$. These add and multiply like polynomials a+bx, but with the convention $i^2 = -1$. In the pairs notation then, $< a, b > + < c, d >=< a + c, b + d >$ and $< a, b > * < c, d >=< ac - bd, ad + bc >$. Thus this is not an ordinary two-dimensional space, but one with some mathematical structure. Complex-valued waves that carry information, not physical properties, have been difficult to represent as a part of known reality. The first awareness-wave model postulates that these waves have components of awareness and something at this stage I just call content. The imaginary numbers quantify awareness and the real numbers quantify content. The physical properties that the waves produce are a combination of these elements. With awareness a part of every quantum wave, models of how experiences can be produced during brain activity become possible.

For a wave with value $a+bi$ at a point, the probability distribution at that point is proportional to a^2+b^2. Thus the real and imaginary parts have equal influence, and the physical properties do not depend on the signs of a and b, just on how far the value is from the silent ground state $0+0i$. Here, strong awareness with weak content is as impactful as weak awareness with strong content. The information is highest with strong awareness and strong content. The awareness model at this point does not say anything about the signs of the two components either. These may or may not mean anything when the implications on experience are worked out, so at this point are not used. That's why this is just the first model. The signs and real vs. imaginary values do make a difference in how quantum waves move and interact, however, and so on how the physical properties evolve. There may be a simple formula like $a^2 + b^2$ for the mental impacts of the wave function as well, or it might use more of the structure of the complex values. Modeling details like that would have to be worked out along with the actual neuroscience models of experience.

A wave-field version of the model has the waves changing values within a complex quantum field. The wave-field version of the first model then is that the real part of the quantum field is a field of content and the imaginary part is a field of awareness. Here content is not specified, and could be considered to be a subtle version of the physical states. Another model would be to have both real and imaginary components being parts of consciousness, which would make the quantum field a field of consciousness. Also it might all be easier to visualize as residing in two extra information dimensions. It is too soon to try to select among these model choices, as they have not yet been calculated for models of neural processes.

Awareness here is defined as the capability of experiencing. The field of awareness does not need to be viewed as a subject. Continental philosophers have sometimes criticized Cartesian duality for not making room for a subject of experience. Descartes did do that separately in his famous derivation "I think, therefore I am." Analytic philosophers, though, have questioned whether a subject is necessary for experience. Russell (1912) generated the retort often summarized as "Thoughts do not necessarily imply a thinker." He was arguing generally about how philosophy misuses language. Strawson (1967) continued this thread by questioning whether existence is a property that some things have and some things don't.

Eastern philosophy has different views of the notion of a subject. Buddhism regards the idea that the self is the thinker/decider as an illusion that disappears in enlightenment. Vedanta philosophy, which predates the religions of South Asia and is not fundamentally a religious approach, holds that in enlightenment the thinking/deciding process becomes part of what is experienced instead of what is being done, while the self identifies as the experiencing consciousness, Atman. This is said to be a state of freedom, intense happiness, and quiet dignity. As enlightenment progresses, Atman is realized to be just a small portion of universal consciousness, called Brahman. Universal awareness is an initially overwhelming experience that takes a few days at least to integrate into normal activity. Vedanta's descriptions of this experience parallel some Western accounts, e.g., James (1902), who considers it as a union of his "spirit" with God's, and Lightman (2018), who doesn't. These are what Vedanta calls the personal and impersonal interpretations of Brahman. Either way, the experience of a universal consciousness seems to be something the nervous system occasionally produces. The self is not a fixed part of life in this philosophy either.

Awareness without being a subject is taken here as simply a component of experience, to be combined with physical inputs as part of thinking and sensory events. Then brain activity, viewed on the micro level, is going on in the quantum field, so has physical and mental aspects. This does not model the physical neural activity as causing the experiences – the physical and mental aspects are simultaneously existing parts of a single process.

Awareness and content are distinct components, and so this is a dualistic theory, but not exactly panpsychic, as awareness is not exactly in the physical world as it is traditionally conceived of. At the same time, both components are parts of the quantum field, which provides a unifying element. This can then be view as neutral monism – both mind and matter are produced by the quantum field.

The awareness-wave models avoid the hard problem of how physical interactions could produce consciousness, and makes physical/mental interaction plausible, but do not by themselves say how these interactions would work to produce our experiences. In the final section, some ideas from neuroscience are discussed, and how these could be developed to explain consciousness using this model is compared to trying to use them under physical monism. Some of the proposals for mental/physical interaction apply a concept from quantum mechanics known as coherence, so that is presented briefly first.

5. Quantum Coherence

Coherence of waves in general refers to correlations among some waves. This can apply to quantum waves. Often coherence is created by the way the waves are formed. A typical example is when a wave hits a wall with two slits in it. As seen in Figure 4, waves emanate from each slit in a correlated way. Where they intersect, the wave heights add, generating an interference pattern caused by the varied combinations of high and low points.

A single electron wave hitting two slits will form a similar pattern, where the high and low

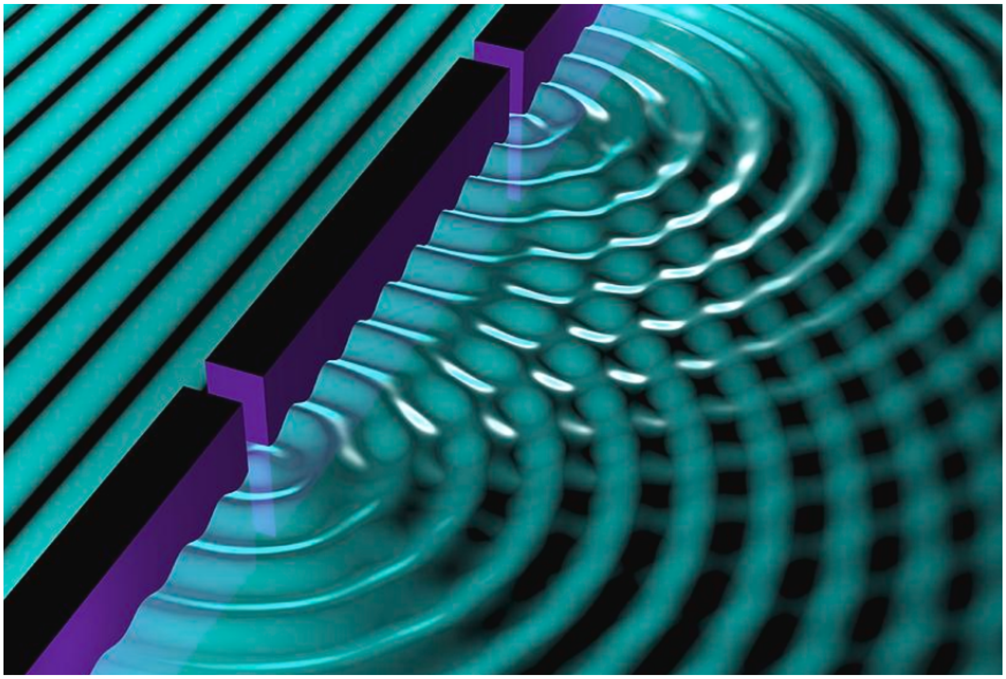

Figure 4: Interference Pattern from Two Slits

values translate to higher and lower values of the wave function, which gives the information distribution. If the waves hit a plate with a relatively fine degree of resolution, the wave will shrink dramatically in accord with the information. If this is done over and over, the interference pattern will show up as bars of few and many hits, corresponding to high and low probabilities. See Figure 5.

For quantum waves, the real and imaginary parts go into this interference pattern. Wave values add, but with such correlation, the probabilities do not. If the wave value at a point is $\Psi = a + bi$, then the probability is $P = |\Psi|^2 = \Psi\Psi^* = (a + bi)(a - bi) = a^2 + b^2$. Here $\Psi^* = a - bi$ is called the complex conjugate of Ψ. The first three $=$ signs here are definitions of the notation. Typically the functions are normalized so that the sum of all the possible probabilities is 1.0.

Denoting two wave functions at a point as Ψ_1, Ψ_2, the wave functions add, so the real number P is given by $P = |\Psi_1 + \Psi_2|^2 = (\Psi_1 + \Psi_2)(\Psi_1^* + \Psi_2^*) = P_1 + P_2 + \Psi_1\Psi_2^* + \Psi_2\Psi_1^*$. Independent variables would just give the probability $P_1 + P_2$, so this equation shows how the correlation arising from the real and imaginary parts affects the probabilities, which show up in the interference pattern.

Figure 5 represents what the quantum model posits. What we observe are the electron waves coming one electron at a time from the left, the two slits, and the interference pattern on the

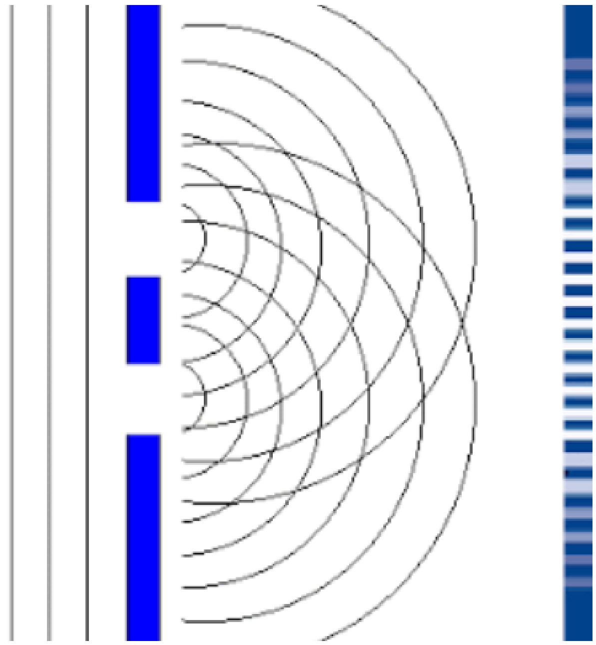

Figure 5: Interference Pattern Hits a Recording Surface

plate at the right. The model explains this as a wave interference pattern. An electron wave goes through both holes and interferes with itself. The higher the resulting combined wave is where it reaches the plate, the higher is the probability of a mark being made there on the plate. The math of the real and imaginary parts of the wave function explains the pattern that shows up after a lot of electrons go through. This has been an enormously successful model and is really the only one we have. That is how we end up with the idea of waves moving through a complex-valued space.

Coherence is correlation that shows up within a single wave function. If two or more waves are correlated, this is called entanglement – but the math works the same. Another quantum effect is electron or proton tunneling. An electron wave can pass through some barriers that would stop a particle. Molecules have vibration patterns, and an electron going through a molecule would pick up vibrational influences which might be used to identify the molecule.

Coherence, however, is delicate and can break down, with the wave function then making random choices, if the wave has much interaction with others. How delicate coherence is and how it breaks down are still being studied by quantum engineering. A popular model of how it breaks down is called decoherence, following Zeh (1970). This was studied throughout the 1980s, and mathematical models now predict how the process will unfold.

Decoherence proposes that information in a coherent wave function is gradually entangled with the environment through interaction with other entities. In a vacuum this might not happen, but in air there are molecules that gradually entangle with the wave and then with other molecules, absorbing some of the correlation. There may be stochastic elements to this process as it unfolds. Eventually the coherence is so diluted that it is not observable anywhere. Empirical measurement of the gradual obliteration of quantum coherence by decoherence is reported in Brune et al. (1996).

Coherence can be created, like in the slit example, which puts detailed information into the wave function. This can be used to store more information in what are called qubits – quantum bits. These use coherence to store 2 bits in a qubit – and a single atom can be made into a qubit. Also entanglement may allow complex interactions, even over some distance, among collections of qubits. Quantum computers using this can be millions of times faster than normal computers on some specific operations, but they are also subject to decoherence. Vacuums, cold temperatures, and magnetic confinement can help prevent information loss through decoherence.

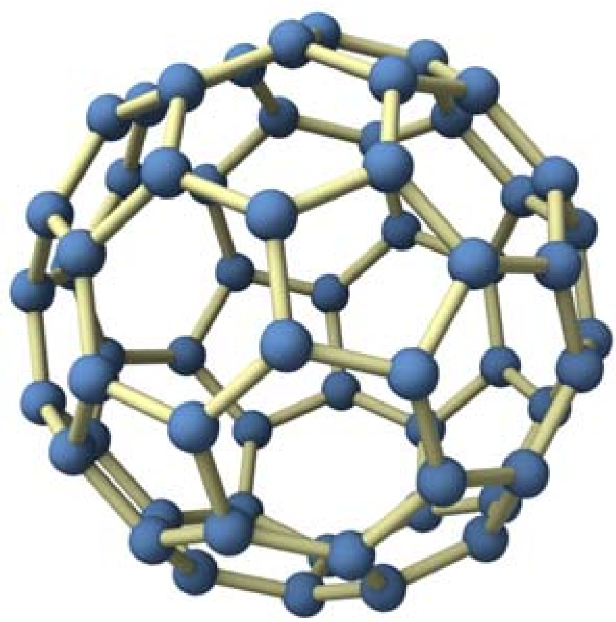

Figure 6: Buckyball

Buckyballs (Buckminsterfullerene) are molecules of 60 or 70 carbon atoms that come in geometric shapes similar to geodesic domes. See Figure 6. They have been used in some coherence tests. The molecule as a whole can be treated as a single wave function. Even though its wavelength is much smaller than the molecule itself, it is possible to produce double-slit interference patterns and other coherence measures for whole molecules in a vacuum. E.g., see Arndt et al. (1999). Hornberger et al. (2003) showed gradual deterioration of coherence for Buckyballs with gradual introduction of small amounts of air. When the atmospheric pressure reached one-billionth of that at sea level, the coherence disappeared entirely. The degree of decoherence was quite similar to what the theory provides mathematically. Even though something as large as a molecule will appear to be a traditionally physical particle, some fairly large molecules can still display quantum coherence in the right circumstances.

An interference pattern that appears with sequences of one electron at a time is the kind of data that required a theory like information waves transversing complex space. Particles do not appear in this theory, but for a long time physicists explored interpretations of quantum mechanics that had the waves turning into particles when they hit the plate. Now it seems to work better to not bother trying to make particles appear, and just accept the theory as is, and think of waves transferring information to the wider environment in some stochastic fashion, like decoherence. In the two slit experiment, most of this transfer takes place when a wave hits the plate. Then the specific momentum and uncertain location become entangled with the plate, leaving the electron wave with widely uncertain momentum and a temporarily fairly specific location that follows the probabilities determined by the wave information. How finely the plate can specify the location may determine how much that aspect of the waves shrinks. At a fine-enough scale – like nuclear – the location on the plate will look like a large spot, so is not a point.

Some theories of how experiences arise with brain activity involve quantum coherence. These assume that awareness-potential somehow is there in the quantum field. Quantum-awareness models make this explicit. They make coherence models of experience plausible, but they do not require coherence to work. One model that doesn't is discussed in the next section.

Panpsychic models already have a lot of bits of awareness around, and some of these models look to how such bits might be aggregated into experiences that we actually notice. Most brain activity is unconscious or subconscious, and some kind of aggregation could make it conscious. Neuroscience research suggests that conscious experience requires coordinated activity across multiple brain regions. That is a kind of aggregation, and may have coherence aspects as well. It also could generate emergent network effects. Complex networks are capable of producing surprising results that are unexpected from the components – called emergent properties. We will also look at these in the next section, which looks at approaches to the interaction problem in the quantum-awareness models.

6. Quantum-Awareness Neuroscience

In this section we look at how quantum-awareness theory used with some of the approaches of neuroscience might model conscious experience, and how much harder it would be to explain consciousness under physical monism, where the hard problem dominates.

a. Emergent properties

Emergent properties are behaviors of complex systems that would not be anticipated given the component parts. Two popular examples are the coordinated activities of ant colonies such as bringing back large amounts food from widespread locations, and the way bird flocks move together in continually changing patterns with no apparent leadership. Both of these behaviors look mysterious given the lack of overall guiding mechanisms, but both have been analyzed in detail, and now can be explained by simple actors following specific simple rules. The emergent properties, while surprising, can be clearly understood to arise from step-by-step mechanisms within the systems. For ants this includes following trails left by others, and leaving chemical signals when food is discovered. The signals disappear fairly quickly, so need to be reinforced to stay in effect. For the bird flocks, following others but sometimes deviating can explain how the flocks move. Thus we can see exactly how these properties emerge from the activities of the individual parts.

Consciousness could be an emergent property of the brain. E.g., see Bassett and Gazzaniga (2011). The brain is indeed a complex system. It contains roughly speaking 100 billion neurons, and there are hundreds and probably thousands of different types of neurons that function and learn differently. There are also chemicals in the brain that affect processing. Millions of neurons are involved in executing complex tasks, and these have intricate connections. Princeton (2020) puts it:

"... each brain cell receives precisely-defined input signals from tens of thousands of other neurons and it sends its own output signals to a different precisely-defined set of thousands of neurons. Many of the neurons with which a given neuron interacts are in close proximity, defining local microcircuits, while others are centimeters away and define a longer-range pattern of connectivity in the brain. This wiring is not at all random; it is exquisitely precise and almost unimaginably complex ..."

It is plausible that a network like that could produce emergent behavior. Fruit-fly brains have been studied intensively. They are much smaller than ours but have similar biology. The behavior of the flies could be considered an emergent property. There is little hint in looking at the individual cells that that the flies' actual behaviors could be produced. And all of it could be theoretically explained by circuits that connect the brain cells to the cells around the body that carry out the behaviors. It seems like detailed mechanisms to show how all of that works could be described given enough time and effort.

Conscious experience is also something that could not be predicted by looking at the nerve cells. Thus it is reasonable to hypothesize that consciousness is an emergent property of brain function. But it is challenging to come up with a detailed mechanism showing how exactly consciousness could be so produced. All those neurons doing all those highly interconnected things is impressive, but a step-by-step way showing how conscious experience emerges is difficult without some form of consciousness already being there to access. This is a version of the hard problem inherent in physical monism. It is not enough to say consciousness is an emergent phenomenon – showing how components could come together to create consciousness is necessary for this to be an explanation. Human behavior would be much easier to explain as an emergent phenomenon. At least all of the mechanisms are clearly in place, even though the details could be incredibly complex.

Coming face to face with the difficulty the hard problem poses leads some physicalistics to deny the reality of experience. You get statements like "Experience doesn't really exist – it is just a kind of hallucination." Or even "We don't really have thoughts – we just think we do." Strawson (2008) finds the denial of experience troubling: "At this we should stop and wonder. I think we should feel very sober, and a little afraid, at the power of human credulity, the capacity of human minds to be gripped by theory, by faith. For this particular denial is the strangest thing that has ever happened in the whole history of human thought, not just the whole history of philosophy."

I am less disturbed. Perhaps optimistically I find it hard to believe that many people could accept anything so self contradictory. After all, hallucination is a type of experience. But Strawson is right to attribute it to faith. Some religions actually take the ability to accept logical impossibilities as a sign of true faith. Adding such a tenet would take physicalistics across the line and make it an actual religion.

Panpsychism, and especially quantum-awareness theory, would make it more plausible that a mechanism could be developed that would show how experience emerges from brain activity. All the inter-related neurons in physical space would result from inter-related wave functions in the quantum field, with projections on awareness as well as on physical space. The mechanism might involve finding coordinated, multiply reinforced, neural activity that creates a cohesive enough pattern in awareness to show up as experience. This could involve quantum coherence or entanglement, but would not necessarily have to if it creates a sufficiently strong information signal.

b. Quantum biology

Physicists long suspected that consciousness is somehow connected to quantum processes. The fact that the quantum waves are more like information carriers than like forces or masses has been part of this sense. But specific formulations of how quantum mechanics might work in the brain remain speculative.

Since the early days of quantum physics there have been ideas about it being involved in life more generally. The term "quantum biology" is found as early as Jordan (1943). A recent review is Offord (2019). Also see McFadden and Al-Khalili (2018). A fundamental problem is that quantum effects usually are so small and fast that they would not affect living things. Some recent work, however, suggests that noisy systems can slow decoherence from taking information from quantum processes. Huelga and Plenio (2013) put it this way:

"Open systems, however, especially warm, wet and noisy biological systems, are subject to environmental fluctuations that are usually expected to result in fast decoherence and, as a result, the suppression of well controlled quantum dynamics. Thus quantum phenomena may at first sight seem unlikely to play a significant role in biology. There are arguments however to counter this pessimistic view. At the level of molecular complexes and proteins, processes that are of fundamental importance for biological function can be very fast (taking place within picoseconds) and well localised (extending across a few nanometers, the size of proteins) and may therefore exhibit quantum phenomena before the environment has had an opportunity to destroy them. Furthermore, early work in quantum information science, for example, has shown that thermal noise in stationary non-equilibrium systems may in fact support the existence of quantum coherence and entanglement."

He cites Plenio and Huelga (2002) and Hartmann, Dur, and Briegel (2002). The idea is that the systems are so noisy in themselves that they do not take information away from the quantum system. The noisy effect is still controversial, but it seems fairly well supported for enzyme action and photosynthesis, for example.

This is involved in some studies that suggest that quantum effects are involved in aspects of perception. One such is the sense of smell in many species. The usual explanation of odor perception is sensors that respond to the shape of molecules from odor sources and use this to send signals to the olfactory brain center. This theory works very well. It falls short, however, in explaining the ability to detect differences between molecules of the same shape. Turin (1996) proposed a quantum process to explain this, involving electron tunneling. Electrons passing through a molecule in a shape sensor can pick up vibrations that distinguish between molecules of the same shape, and this information gets sent to the olfactory center.

Tests of this have been developed using deuterium as a substitute for hydrogen in some molecules. Deuterium is a heavier variant of hydrogen that has a neutron in each atom. Franco et al. (2011), and others, found that fruit flies can detect this change. Some studies found that people cannot, but more recently, Gane et al. (2013) found that in some cases we can. A quantum explanation of this behavior is still controversial, however, in part because slower decoherence in noisy systems is not universally accepted. Also the shape theory can be tweaked with add-on mechanisms to explain some of it. Behavioral predictions are not regarded as being as convincing as purely physical experiments would be when new mechanisms are involved. One more-physical mechanism being proposed as a test is to make a mechanical nose to detect airborne particles by measuring tunneled electrons. See Patil, Saha, and Ganguly (2018).

Another place that quantum effects are thought to show up in sensory perception is in the ability of birds to detect the direction of the Earth's magnetic field. Ritz, S. Adem, and Schulten (2000) suggest a process involving entanglement to explain this. They propose that a blue-light photoreceptor called cryptochrome in the birds' eyes reacts differently with different orientations to the magnetic field, and that this is due to the way the orientation affects pairs of entangled molecules. This happens by the radical-pair mechanism. Electrons in molecules usually come in pairs. A molecule with an unpaired electron is called a radical, and it reacts easily with other molecules. When a molecule in a cryptochrome receptor reacts with a radical, the two become a radical pair, and typically have correlated spins. (Spin is one of the fundamental properties of micro matter.) The radical pair soon reacts, often just reverting to its original molecules. But before that happens, the magnetic field will change some of the properties of the pair's spin relationship, and this will occur in somewhat different ways with different orientations of the bird to the magnetic field lines. The reverted molecules then have paired spin properties determined by the orientation, and this information can be detected and passed along in the birds' brains, giving them different visual experiences with different orientations. This view is gaining support. Kominis (2015) provides a more recent perspective.

Even now, quantum effects in biological systems are not universally accepted, but there is some strong empirical support. This gives a degree of credence to the possibility of quantum effects in consciousness experience. Two specific proposals from this perspective are reviewed.

The first is from Hameroff and Penrose (1995), with a more popular-level summary in Hameroff (2019). It starts with the idea that decoherence will occur spontaneously in large-enough collections of entangled particles. This is called OR, for objective reduction, and the authors propose that such events produce consciousness. They further propose that this takes place within microtubules, which are structures inside of neurons. The rigid microtubules give a degree of fixed shape to the neurons and also do some information processing. They are built from a protein called tubulin. These physicists propose that the tubulins contain sets of electrons with spins in a quantum superposition of states, forming qubits, and that these qubits are entangled with those in other tubulins. When about a billion of them are entangled, OR will occur in an orchestrated way that they call Orch OR, producing experiences. This can all take place in a single neuron. Complex networks of neurons then produce continuous experience. They give a variety of possible physical mechanisms for all of this, and ongoing research is attempting to chase them all down. They remain optimistic that some of these will come together into a full account, but much of the physics community is skeptical.

This approach largely avoids the hard problem, as they presume that consciousness exists as a potential in quantum systems. They do not suggest any structure of quantum fields that would incorporate consciousness specifically. Quantum-awareness models could provide a path towards that. The activities of Orch OR in the imaginary dimension would be an account of what is happening on the mental side. Differences in that across neuron states would then be the mathematical representations of those experiences. If that produced systematic patterns among different experiences, a quantum-awareness model would help model that process.

The second proposal is from Fisher (2015). Fisher is an award-winning quantum physicist who is looking into ways that long-lasting qubits could be created in neurons. One step towards this is using qubits from nuclear spins, which are more stable than electron qubits. Another part is how the qubits might be protected from interactions that would produce decoherence. Phosphorus atoms can hold qubits, and a molecule with 9 calcium atoms and 6 phosphates, called the Posner molecule, can have 6 qubits. The coherence in the atomic nuclei are protected from decoherence by their electron clouds. This is a different way of maintaining coherence that does not require noisy systems.

Fisher (2015) says "Multiple entangled Posner molecules, triggering non-local quantum correlations of neuron firing rates, would provide the key mechanism for neural quantum processing. ... The uptake of many Posner molecules could induce nuclear spin entanglement between multiple presynaptic neurons." He also proposes a mechanism for transportation of the entanglement across synapses to other neurons. This would lead to nuclear-spin quantum processing in the brain.

Fisher does not connect this directly to consciousness. He is focusing on physical accounts for neural activity and its behavioral impacts. He thus avoids the hard problem by staying away from explicitly predicting conscious experience. Still the pieces are there as long as consciousness is already a part of quantum waves. Quantum-awareness models could provide a link to this. Fisher's proposed process would produce correlated activity in both physical and mental wave components, which could produce neural and mental states. Enough such correlated activity in mental components would also produce an accumulation effect that could dominate the background noise and produce clear thoughts and sensory experiences.

Fisher's work has of course generated skepticism, but also enthusiasm, including funding for further research. He is now scientific director of the Quantum Brain Project, which has researchers in several universities testing the mechanisms he has proposed.

c. Aggregation

Any model that has consciousness already there in some form, like panpyschism, quantum-awareness theory, or any kind of dualism, has to deal with the issue that most brain activity does not make it into our awareness. One approach to this is aggregation, where the component bits of consciousness sometimes compile in a consistent way enough to get noticed. Some recent research in neuroscience suggests a possible path to that.

One direction in consciousness studies is to use MRI, etc. to observe brain activity in subjects able to adjust to and/or report experiences from a variety of stimuli. Dehaene and Changeux (2011) review several such studies. They find support for the Global Neuronal Workspace (GNW) model "according to which conscious access occurs when incoming information is made globally available to multiple brain systems through a network of neurons with long-range axons densely distributed in prefrontal, parieto-temporal, and cingulate cortices." The information thus goes to many different areas of the brain simultaneously. One conclusion: "Those data suggest that conscious access causes a major change in the global availability of information, whether queried by objective or by subjective means . . . ." They do not propose any process for how this neural activity causes the reported consciousness, but they are finding its neural signature. They also suggest that these processes change the dispersion of information. Part of their findings is massive repetition of similar patterns, which is a form of aggregation.

Sending an incoming signal simultaneously to diverse parts of the brain is a key element. "GNW neurons amplify and maintain a specific neural representation. The long-distance axons of GNW neurons then broadcast it to many other processors brain-wide. Global broadcasting allows information to be more efficiently processed (because it is no longer confined to a subset of nonconscious circuits but can be flexibly shared by many cortical processors). . . (T)he advancing feed-forward wave amplified its own inputs in a cascading manner, quickly leading the whole stimulus-relevant network into a global self-sustained reverberating or 'ignited' state." That shows up in co-ordinated brain-wave activity across regions: "This ignition was characterized by an increased power of local cortico-thalamic oscillations in the gamma band and their synchrony across areas." More specifically, they find "long-distance cortico-cortical synchronization at beta and gamma frequencies."

Even basic visual perception seems to involve large-scale integrated processing. This was brought to light a few years ago by the image known as The Dress – Figure 7. Some people see this as gold and white, and others as blue and black. This has been explained as an actual blue and black picture that is seen differently by people who are usually exposed to lighting that is weighted towards the blue end of the spectrum. E.g., see Rogers (2015). Their brains have developed a habit of subtracting blue from visual images, which in this case gives the experience of gold on white. But that means that a complex integrated process is involved even in just looking.

Figure 7: The Dress

Lou, J.P.Changeux, and Rosenstand (2017) take the GNW results and look for brain activity that causes conscious experience. That is, they look into what brain activity is necessary and sufficient for consciousness. They find that a network of neural hubs is involved. Consciousness "is correlated with a paralimbic network of medial prefrontal/anterior cingulate and medial parietal/posterior cingulate cortical 'hubs' and associated regions. Electromagnetic and transmitter manipulation have demonstrated that the network is not an epiphenomenon but instrumental in generation of self-awareness."

Even though they are finding necessary and sufficient neural inputs for conscious experience, this work does not address the hard problem. It does not provide a mechanism that explains how experience could come from such neural activity. But the hard problem is not a problem of neuroscience per se. It is only a problem for physical monism. This neuroscience direction could work within a dualistic framework. Panpyschism often looks for aggregation mechanisms, and brain-wide replication of a signal is such a mechanism. This would be similar in quantum-awareness models. Even without quantum coherence, all of this long-distance synchronized activity in physical space could be associated with synchronized activity in the full quantum field. More detailed models of the molecular activity within the nerves would be needed to formulate this precisely.

7. Conclusion

The successes of Newtonian physics led some scientists into an overriding faith in causation and a purely physical reality. The unshakable physicalistic faith makes the not-purely-physical aspects of quantum mechanics difficult to accept at face value, and so unnecessary interpretations of quantum mechanics arose to defend those perspectives. Giving up attachment to the idea of "solid, massy, hard, impenetrable particles", as well as to strict causation, leaves a world-view in which quantum waves change shape in stochastic ways but continue moving. A wide wave could go through a shrinkage stage and make a relatively small spot appear on a photographic plate, but it is always a wave.

Cartesian dualism has been studied for four centuries, and in that time no credible proposals have arisen for how consciousness could be created from matter. That is the hard problem for physical monism. Its advocates still hold out hope that a solution might appear once we know more about neurophysics, surely within the next four centuries. Like with the second coming, the delays have been engendering skepticism.

Quantum mechanics contains stronger rays of hope for dualism. If consciousness already exists, we have the lesser problem of how it can interact with matter. Quantum waves are not purely physical, being more like information than physical forces. They have long been thought to have some relationship to consciousness, and the interaction problem comes down to information interacting with consciousness, which does not seem insurmountable.

Having consciousness as part of the wave function would make neurophysical explanations of consciousness a lot easier, and quantum mechanics provides an opening for this, as what the waves actually are is not specified. The quantum-awareness model says that quantum-information waves consist of awareness and content as their imaginary and real components, with physical and experiential phenomena as their projections on these two areas. An alternative model with both components being aspects of consciousness was also discussed. Further development might come up with roles for positive vs. negative values. The original form is a type of dualism, but awareness and content are both parts of a more-encompassing entity – the wave itself – making this a form of neutral monism. The physical probabilities from this information do not distinguish between the real and imaginary components nor positive and negative values. The mental impacts might use more of the whole information.

The model ties quantum waves to familiar things like objects and experiences, and so represents them within the world of our daily lives. It puts awareness directly into the models of physics, and is more specific about that than are panpsychism and other forms of dualism. It is also more specific than proposals that have consciousness somehow associated with the quantum field. Thus it is a way for models from quantum neurology to link physical processes with conscious experience.

By having awareness expressed mathematically as a part of quantum waves, quantum neurologists could compute the effects of proposed processes on both the nerves and experience. Something like a threshold effect, for example, could show a consistent large effect of specific neural activity on experience. That would be a plausible account for how experience arises, much like aggregation tries to be in a less formal way for panpsychism. It might be possible to link that to subjects' reports of their experiences. The models introduced here are not very specific and would need more development in conjunction with models of the quantum aspects of neural processes. What it comes down to in practice is looking at the real and imaginary parts of neural wave activity for consistent patterns through which the awareness components could be entangled or aggregated. The awareness-wave models provide a path forward for modeling consciousness in neural activity and so far there are not many such.

A popular idea is that experience is an emergent effect of complex neurological systems. This seems likely, but emergent effects are not magic – they have to be produced by detailed mechanisms – in the physical monism case one for creating consciousness out of physical processes. Some neurological approaches for how brain activity could generate experiences through quantum awareness are discussed in Section 6. Such models provide ways to show how consciousness emerges from brain activity.

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